When FTM Discovered MUSIC: Accurate WiFi-based Ranging in the Presence of Multipath

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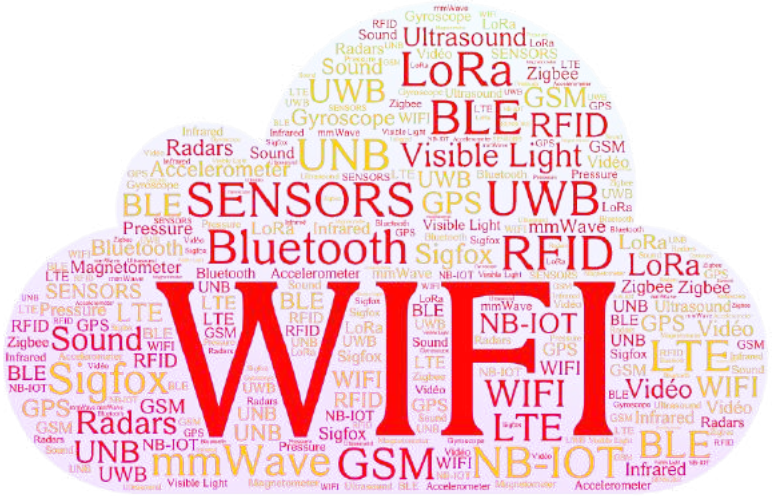
Indoor Localization: a long pathway

- ❑ Two decades of work !
- ❑ Multiple technologies have been used
- ❑ It however remains an unsolved problem
- ❑ A great majority of works around WiFi because it is ubiquitous
- ❑ The core problem in these works is accurate Ranging (to enable Multi-lateration)



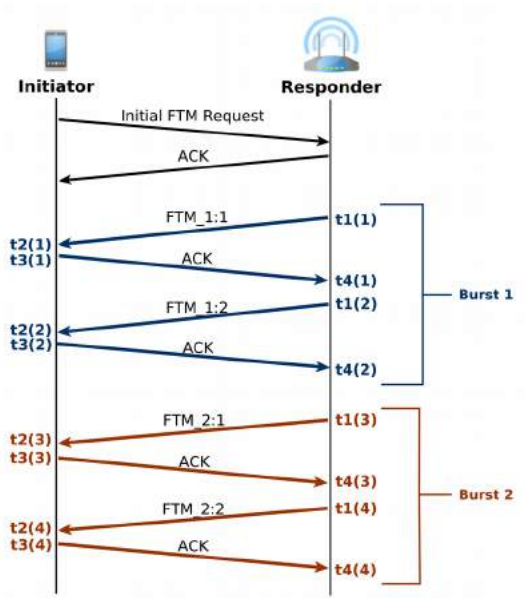
WiFi-based Ranging: Key approaches

- Received Signal Strength Indicator (RSSI) based
  - Uses the signal strength and a propagation model to estimate the traveled distance
- Time-Of-Flight (ToF) based
  - Computes the ToF using timestamps on packets or other low-level information: Channel State Information (CSI) for example
- Both approaches can be very accurate (decimeter-level in some recent works)
- But are currently difficult to adopt in real-life usage: would need to upgrade all existing WiFi infrastructures

Fine Timing Measurement (FTM) protocol: The IEEE Solution

- IEEE 802.11-2016 (802.11mc amendment)
- Well defined exchange of packets (Two Way Ranging)
  - Implemented in the firmware
  - High precision clocks
- Promises a precision of ~1-2m
- Already supported by major WiFi equipments manufacturers and Android OS
  - Google Pixel 2+ phones for example

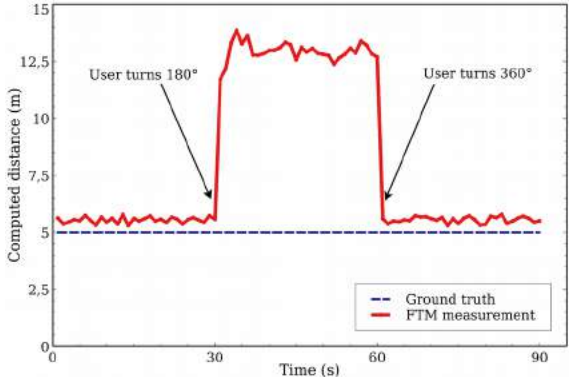
Has a great potential !

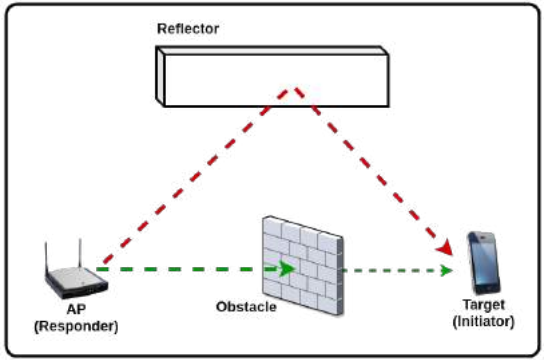


$$RTT = \frac{1}{N}\sum_{i=1}^{N}\left(t_4(i) - t_1(i)\right) - \left(t_3(i) - t_2(i)\right)$$

FTM: The Obstructed LOS Problem

- Accuracy collapses when the user is between the Initiator and the Responder: error of up 9m
- Experimental setup:
  - Presence of a wall at 8m
  - From t=30s to t=60s, the user stands between the two equipments
- FTM seems to be measuring distance based on a (longer) reflected path
- There are questions left unanswered:
  - The origin of the issue: Multipath or relative permittivity ?
  - How to solve the issue ?

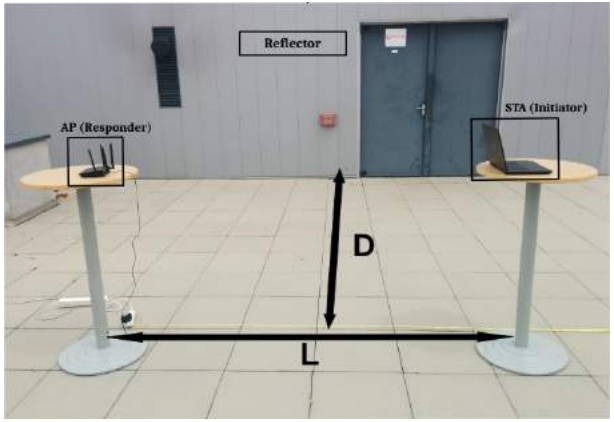


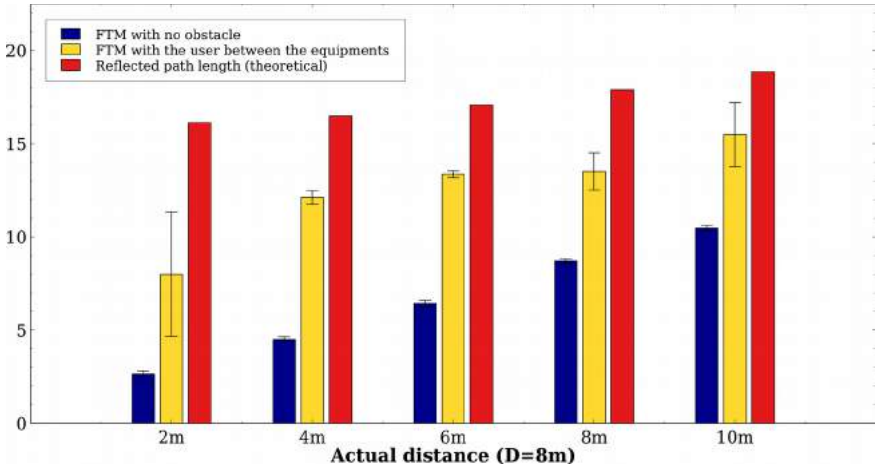


Outline

- ❑ Indoor Localization and WiFi-based Ranging: Key approaches
- ❑ FTM: First Experiments
- ❑ **Problem Assessment**
- ❑ FUSIC: Our solution
- ❑ Performance Evaluation
- ❑ Conclusion

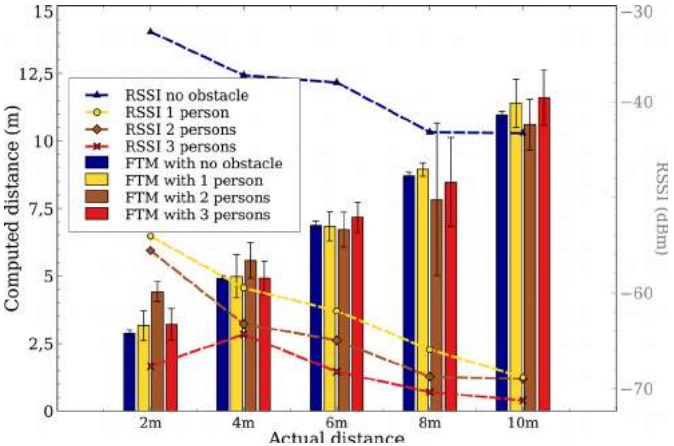
Obstructed LOS in the presence of Multipath





- ❑ FTM is inaccurate when the LOS is obstructed
- ❑ FTM output is between direct and reflected paths lengths

Obstructed LOS with no Multipath

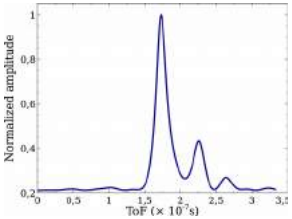


- ❑ RSSI decreases with the number of persons
- ❑ But FTM result is almost not affected
- ❑ Effect of Relative permittivity is negligible → The greatest problem is Multipath

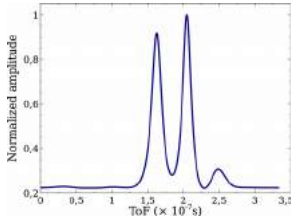
Varying the number of human obstacles in the presence of Multipath

- Same semi-controlled experimental setup as before
- We collect CSI (Channel State Information) with a computer placed near the responder
- CSI are fed to MUSIC algorithm to obtain a PDP (Power Delay Profile)

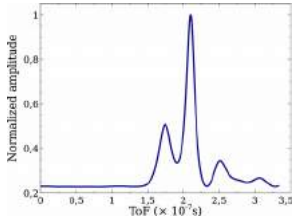
The error depends on the relative strengths of the direct and reflected paths



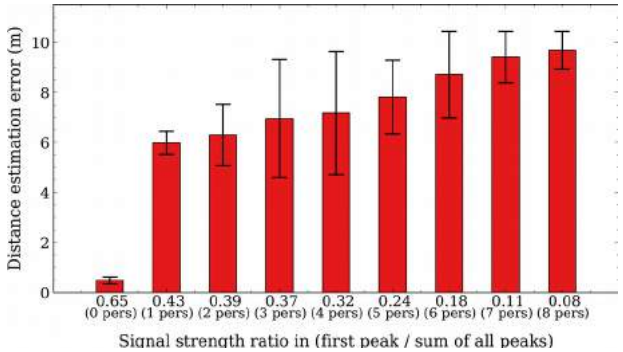
Almost no error



Low error



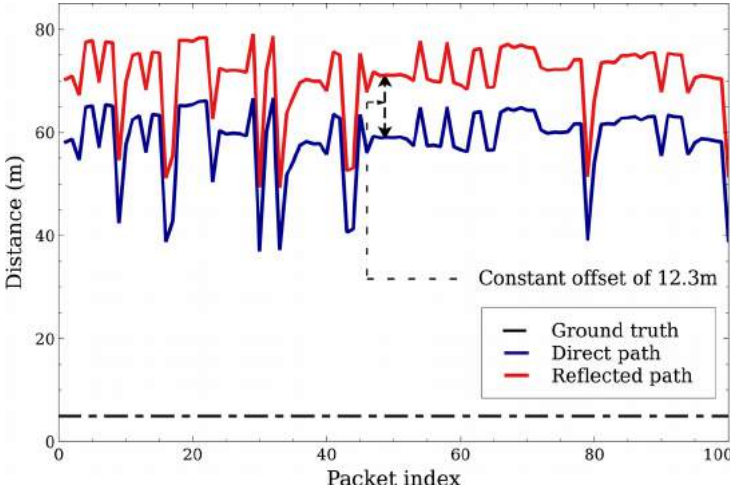
High error



MUSIC and the inaccuracy problem

- Experimental setup:
  - Two equipments separated by 5m
  - A reflector (wall) at 8m
  - We send a series of 100 packets
- MUSIC estimation of distance is inaccurate (~12 times the actual value on average)
- The error is highly variable from one packet to another ==> Static calibration not possible

But, the difference between the two paths is constant and correct across all the packets



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FUSIC: Our Solution

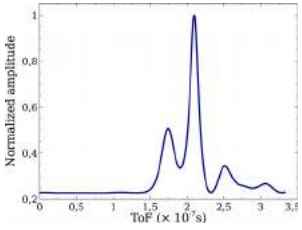
- An algorithm Fusing FTM and MUSIC, both erroneous, to provide accurate Ranging even in the presence of multipath
  - Requires no changes to the standard
  - Requires no changes to the access points
  - Can be implemented as an application on the user's device

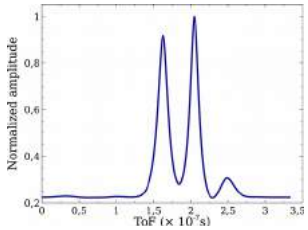
- Takes as inputs the FTM output and the CSI matrix and outputs a corrected distance estimation

- Faces two important challenges:
  - Detecting when FTM is mislead
  - Actually correcting it and returning the length of the direct path

FUSIC: Detecting when FTM is mislead

- Data shows that FTM is mislead when the direct path is not the most dominant one
- Existence of non trivial cases





- We introduce a new metric, R, which quantifies the contribution of the direct path

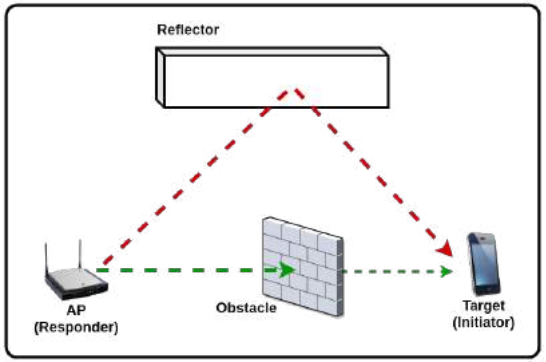
$$R = \frac{P(\tau_1)}{\sum_{k=1}^{K} P(\tau_k)}$$

- Trigger the correction algorithm only when R is below a threshold
- Selecting a value for the threshold: interesting trade-off

FUSIC: Correcting the FTM Output

Let's consider a special case

- Assume we have only 2 propagation paths, with the LOS being strongly obstructed
  - FTM will output the length of the reflected path
- Our goal is to compute the error $d_{reflected} - d_{direct}$
- MUSIC is inaccurate, but gives us the correct value Δ_{ToF}
- FUSIC outputs $d_{fusic} = d_{ftm} - \Delta_{ToF} \times c$



FUSIC: Correcting the FTM Output

General purpose algorithm

- In practice, there may be several propagation paths
- FTM measurements does not necessarily reflect the length of any particular path
- We compute the error as function of all the paths: the mean excess delay

$$\bar{\tau} = \frac{\sum_{k=1}^{K} P(\tau_k)(\tau_k - \tau_1)}{\sum_{k=1}^{K} P(\tau_k)}$$

- FUSIC outputs $d_{fusic} = d_{ftm} - \bar{\tau} \times c$

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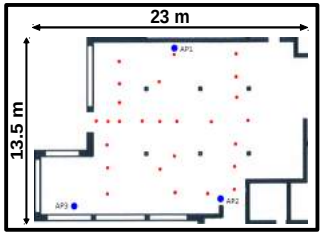
Experimental Setup

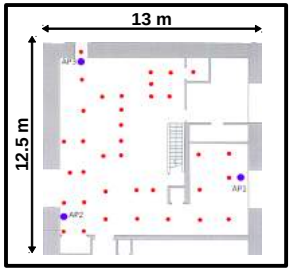
- We use 3 FTM-capable routers and add each of them a computer which reports CSI
- Evaluation in 4 environments: the same semi-controlled one and 3 real indoor buildings
- A total of 122 tested target locations in indoor buildings
- Evaluation of accuracy in distance estimation and indoor localization

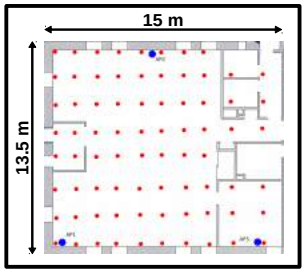
University restaurant

Warehouse

Lounge

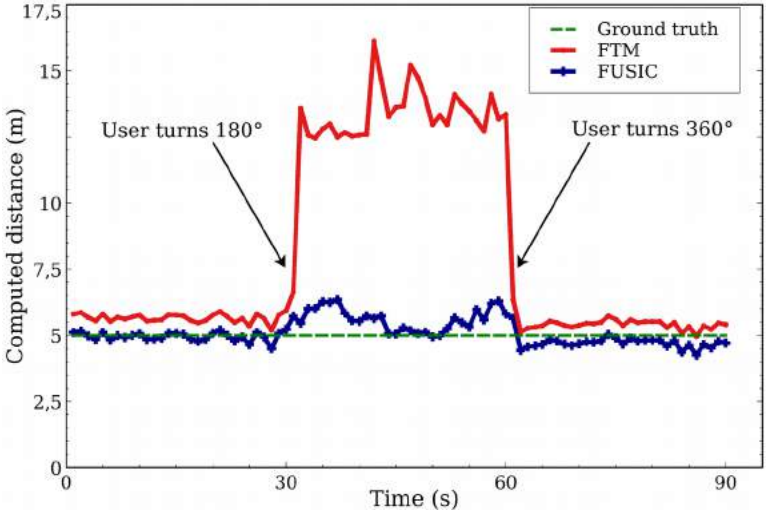




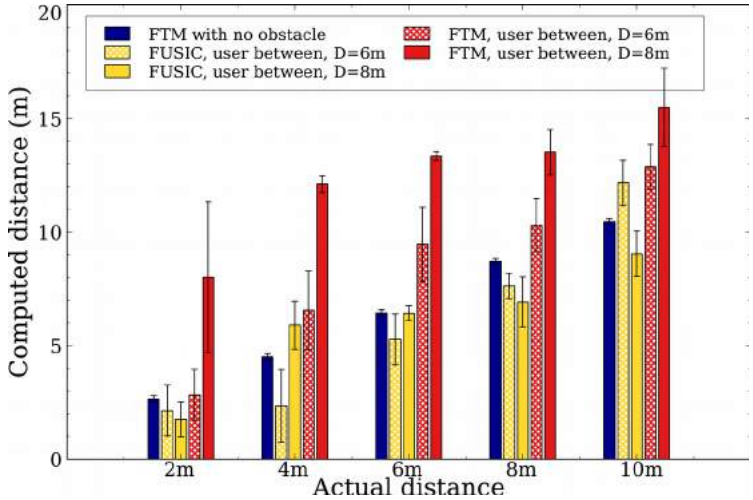


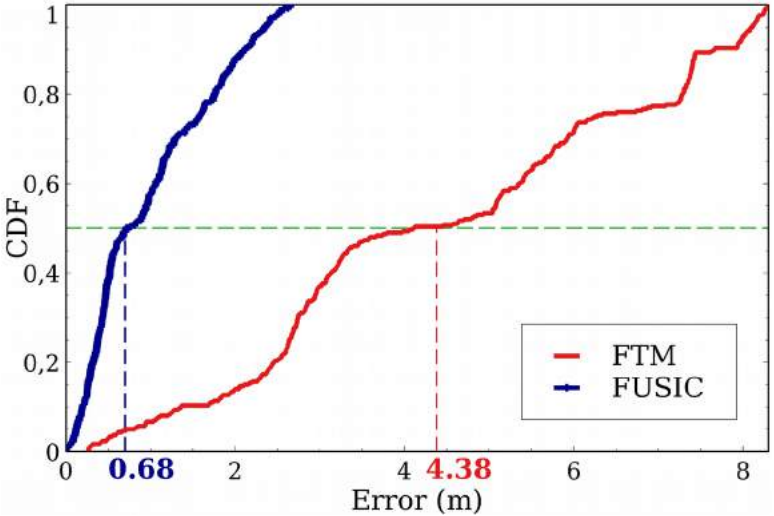
Let’s come back to the beginning

- Same time-variant experiment as before:
  - Presence of a wall at 8m
  - From t=30s to t=60s, the user stands between the two equipments
- FUSIC is able to accurately estimate the distance during all the experiment
- This is not the case for vanilla FTM



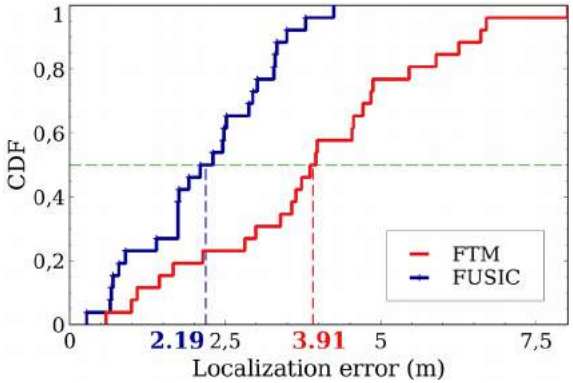
Varying distance between the equipments and to the wall



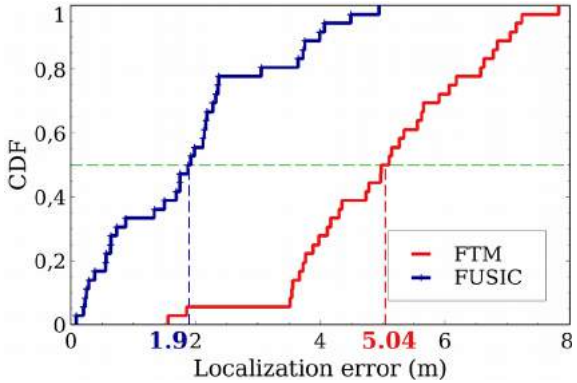


- FUSIC significantly outperforms vanilla FTM
  - Median error: 0.68m vs 4.38m
  - 90-percentile: 2.12m vs 7.8m

Localization in Indoor Environments



University restaurant



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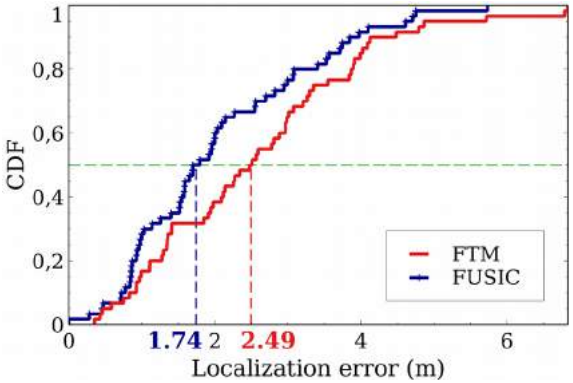

Lounge

- Accuracy in distance estimation ==> Accuracy in localization
  - Median error: 1.94m vs 3.64m
  - 90-percentile: 3.77m vs 5.79m
- Very important difference in the warehouse (most challenging multipath environment)
- Least difference in the lounge

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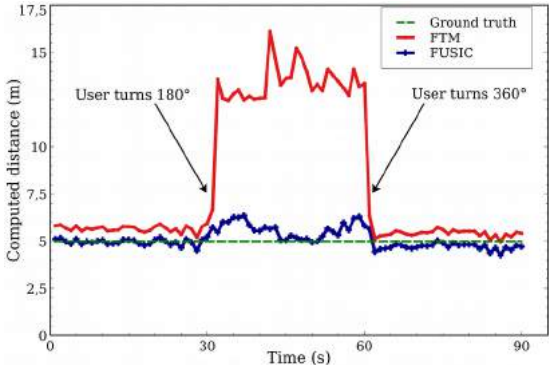
Conclusion & Future Work

- ❑ Assessed the root causes of FTM inaccuracy in Non Line-Of-Sight settings
- ❑ Introduced FUSIC, an algorithm which extends FTM's Line-Of-Sight accuracy to Non Line-Of-Sight settings
- ❑ Implemented FUSIC on off-the-shelf hardware and evaluated its performance
- ❑ Evaluation shows that FUSIC achieves its goal
- ❑ **Future work:** Evaluation of FTM/FUSIC based localization in a real and large scale deployment



Thanks for your kind attention.

Any question ?